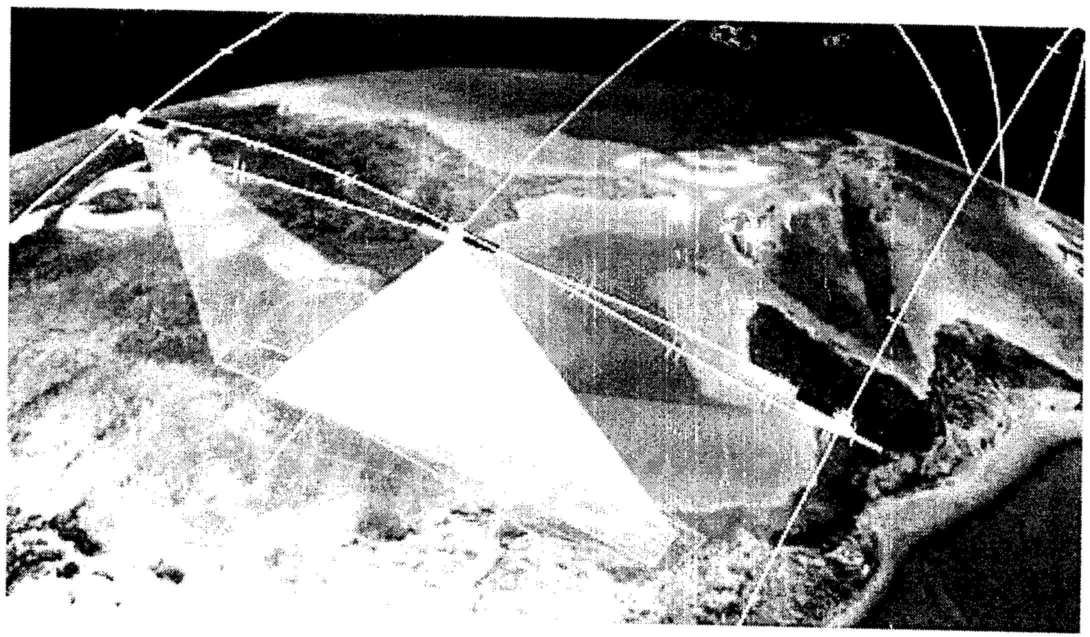
The Techsat-21 Autonomous Sciencecraft Constellation

Steve Chien • Rob Sherwood
Jet Propulsion Laboratory



Outline

- Technology Overview
- Techsat-21 Mission Description
- Autonomous Sciencecraft Constellation (ASC) Demonstration Scenario
- Onboard Technology Descriptions
  - Science
  - Planning
  - Execution
  - Fault Recovery
  - Constellation Management
- Status
- Summary

ASC Team

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Key Software Technologies

- Onboard Science (JPL)
  - Feature detection & change detection
  - Enables onboard decision-making based on science
- Onboard Planning (JPL)
  - Enables onboard development of new plans in response to science events
- Robust Execution (ICS/AFRL)
  - Enables robust plans to deal with run-time uncertainties
- Model-based Mode Identification and Reconfiguration (MIT SSL/ICS)
  - Enables timely state estimation and low level control
  - Technology elements developed at NASA Ames
- Cluster Management (PSS/AFRL)
  - Enables onboard maneuver planning and execution

Technology Impact of Onboard Processing

- New Millennium ST-6 Project Demonstration
  - Six month workstation/breadboard prototype August 2001
- Flight implementation: Sept. 2001 – Sept. 2003
- Operations: Sept. 2003 – Sept. 2004

This flight will demonstrate:

- Vast improvements in science for fixed downlink
  - *Downlink only highest value science images*
- Observation of short-lived science events
- Reduced downtime due to anomalies
- Reduced setup time via exploitation of execution feedback

Techsat-21 Mission

- Air Force Research Lab 3 satellite configurable constellation
- Spacecraft separation 100 m - 5 Km
- 1 year mission, possible extension of 1 year
- High relative positioning accuracy (~ 1 cm)
- 28.5-60° inclination, 600 Km orbit (+/- 20 deg lat)
- 90 minute orbit, ~1-day repeat track
- Each spacecraft has an X-band synthetic aperture radar (SAR)
- ~1 m radar resolution (range and x-range)
- Backscatter of X-band wavelength can easily distinguish water, ice, land (fresh v. old lava)

- Non-repeat pass interferometry possible due to simultaneous emission and receipt of all three spacecraft using orthogonal waveforms
  - Not used for ASC demonstration due to computational cost of onboard interferometric processing

Techsat-21 Demonstration Goals

Program Objectives

Fly in formation

Merge sensor data from 3 sats

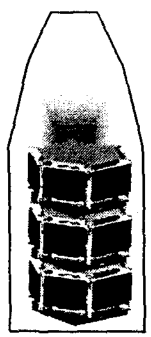
Assess future mission utility

Experiment Objectives

- Fly multiple formations - linear, circular, other
- Know relative position to ~1cm
- Gradually apply full autonomous formation control
- Test out new algorithms for different sensor modes
- Involve Users to generate high value experiments

Flt Experiment Configuration

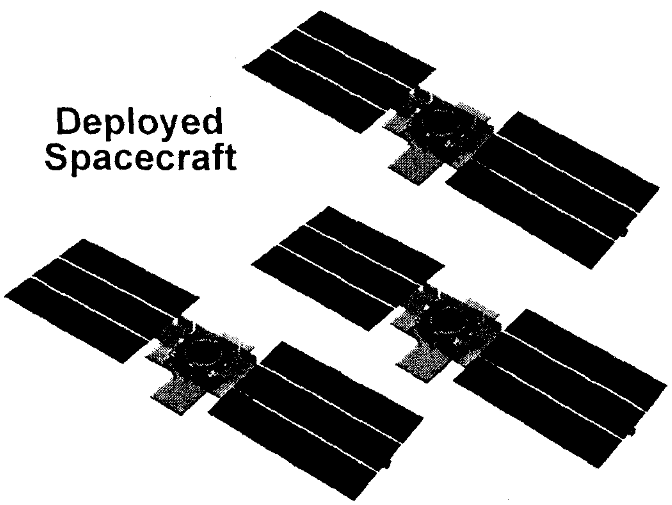
Three independent, LEO microsatellites (150kg each)



Stowed Spacecraft

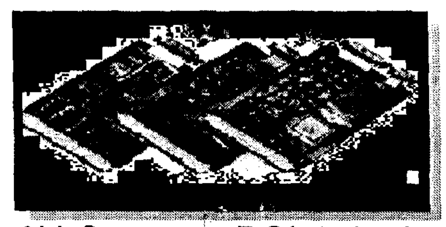
1.1m wide x 0.7m high

Deployed Spacecraft

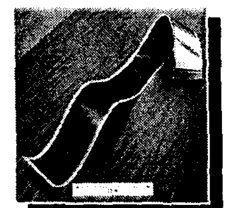


TechSat 21 Formation

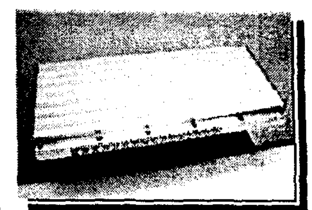
Advanced Subsystems



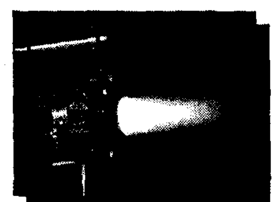
3U Compact PCI Avionics



Thin Film Solar Array

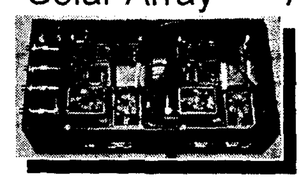


Phased Array Antennas

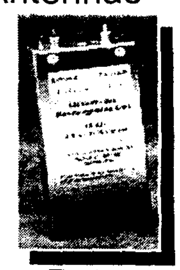


Hall Effect Micro-thruster

Inflatable Boom



Carrier Phase Differential GPS



Li-Ion/Li-Polymer Battery

Techsat-21 Flight Environment

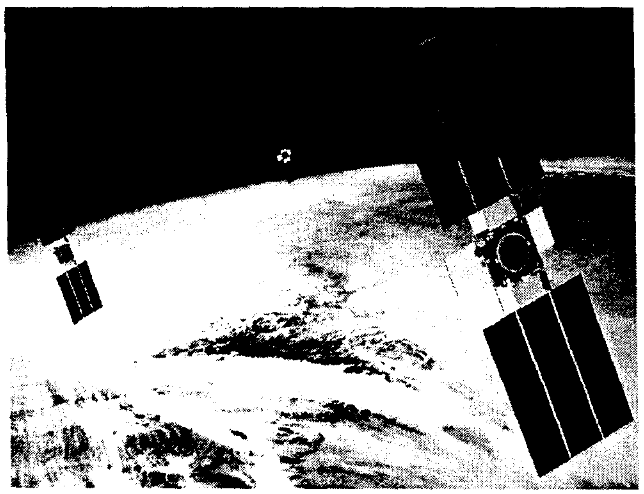
- General purpose flight processor PowerPC 750
    - 175 MIPS machine developed by Lockheed-Martin
    - 128 MB RAM
    - Basic flight software estimated to use 10% of CPU
    - Runs OSE Operating System (by Enea)

- The science data storage memory to CPU RAM interface is slow (56 KB transfer rate)
    - Radar data is approx. 4 MB per image, leads to 23 minute transfer times
    - Will require reduced images be taken for science experiments

Demonstration Scenario

Demonstrate that *onboard processing* can dramatically improve science return

ASC Mission Scenario

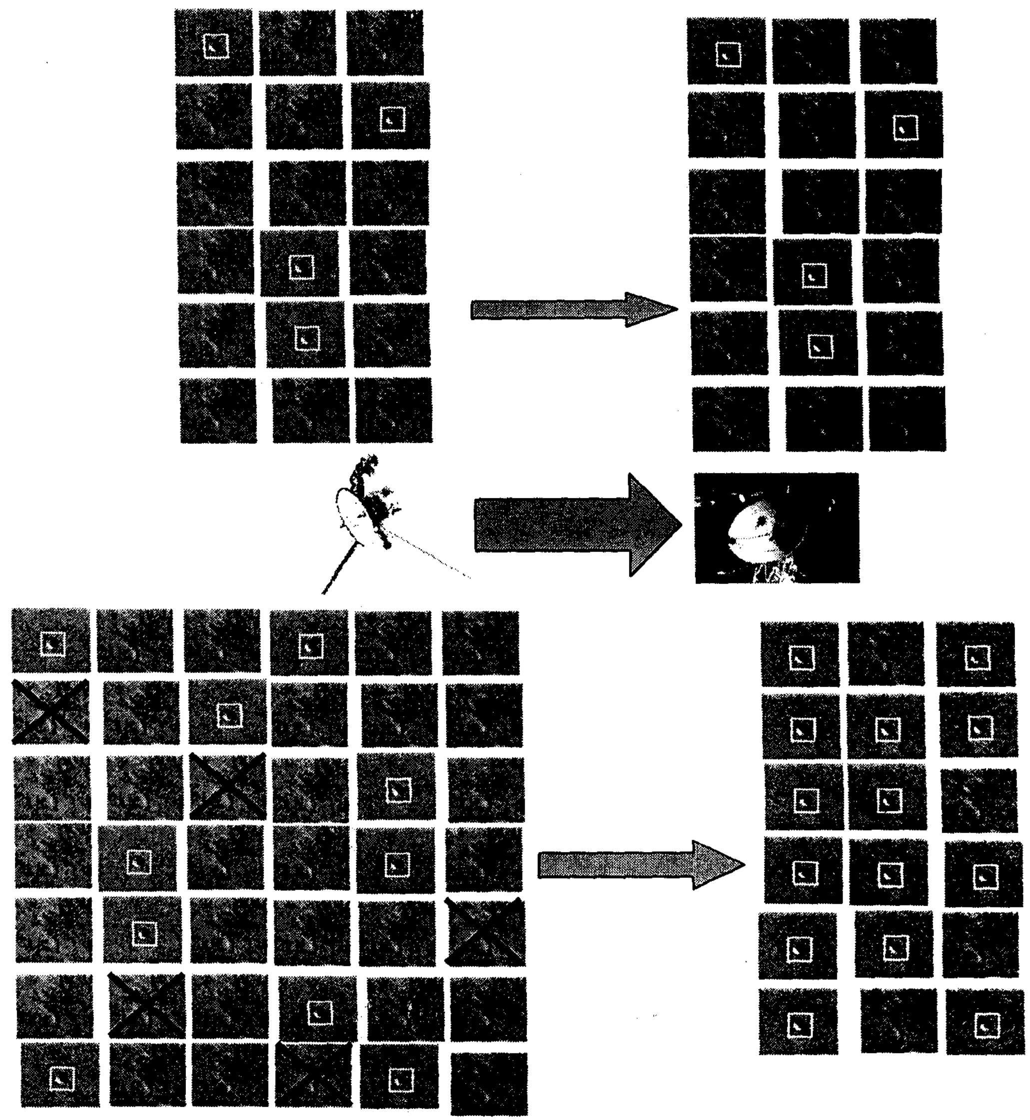


Why fly autonomy software onboard?

- Utilize limited downlink resource

Old Way:

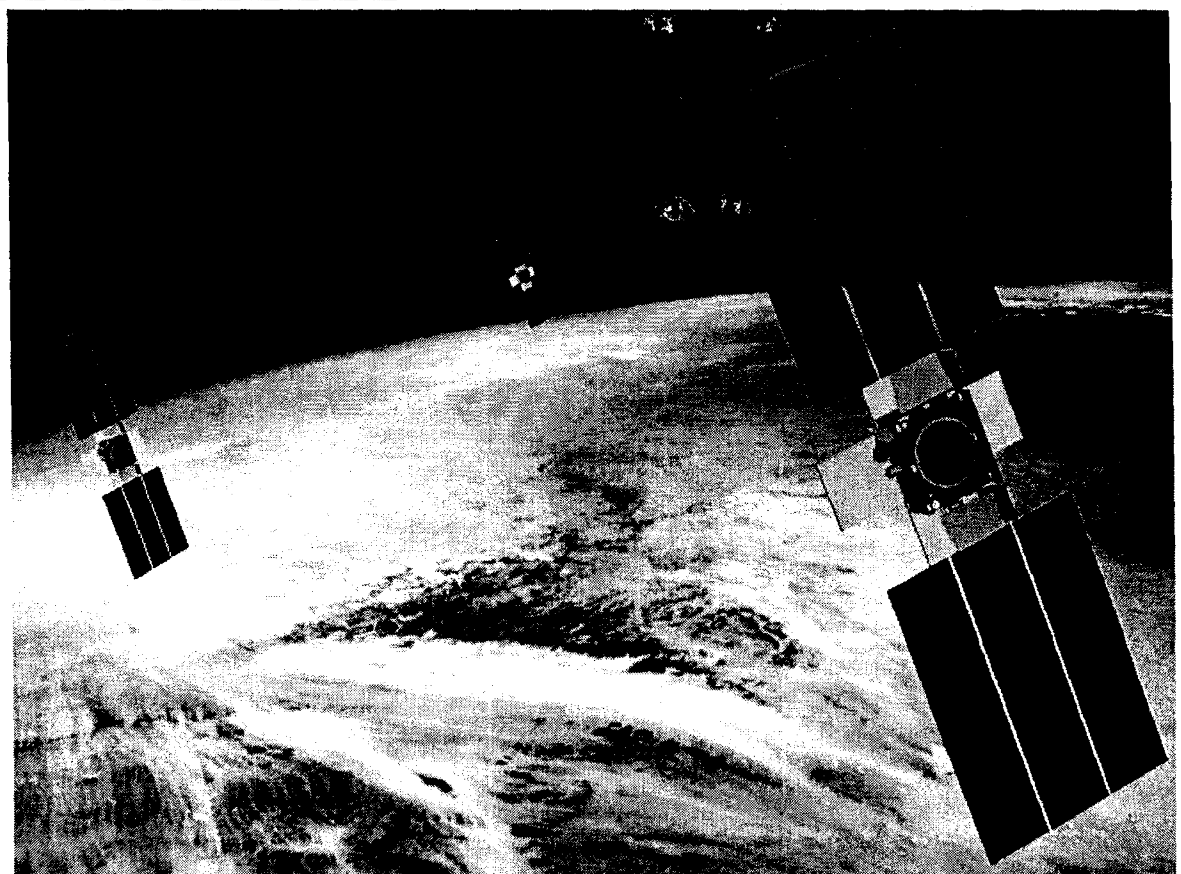
- Take 200 Images
- Downlink 200 images



New Way:

- Take 2000 Images
- Downlink best 200 images
  - only most scientifically interesting portions

Phased Demonstration



Technology Components: Onboard Science

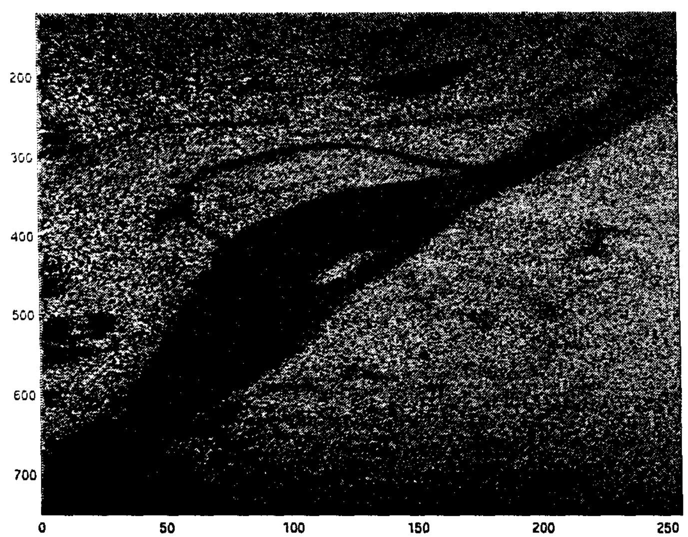
Technology Components: Onboard Science

- Onboard Image Formation software

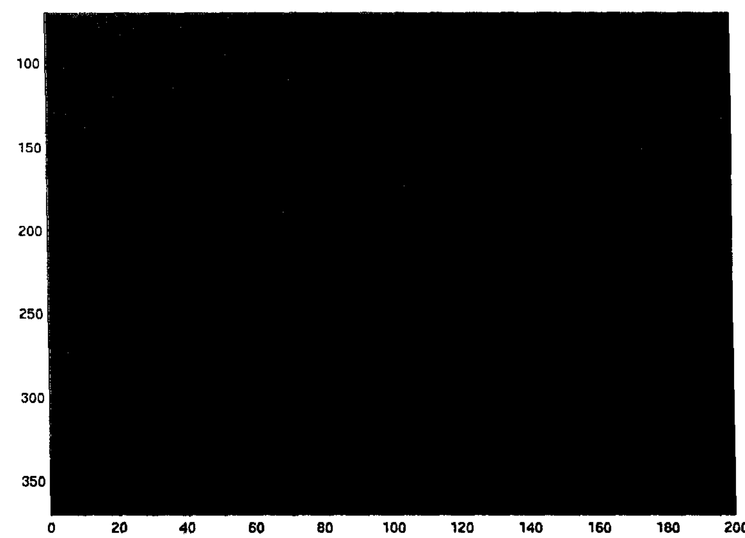
- Onboard Science Components
  - Change recognition software
  - Feature recognition software (looking for specific patterns)
  - Discovery software (generalized recognition algorithm)

Image Formation

- Develop/port algorithms for onboard SAR Image Formation
  - Prototype algorithms in testing on X-SAR data



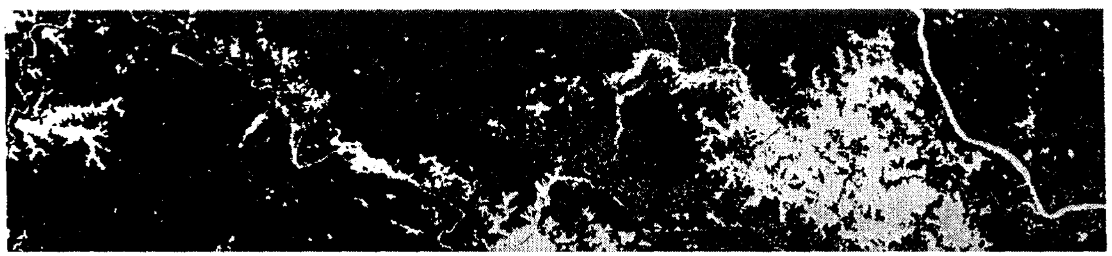
Onboard Software Image



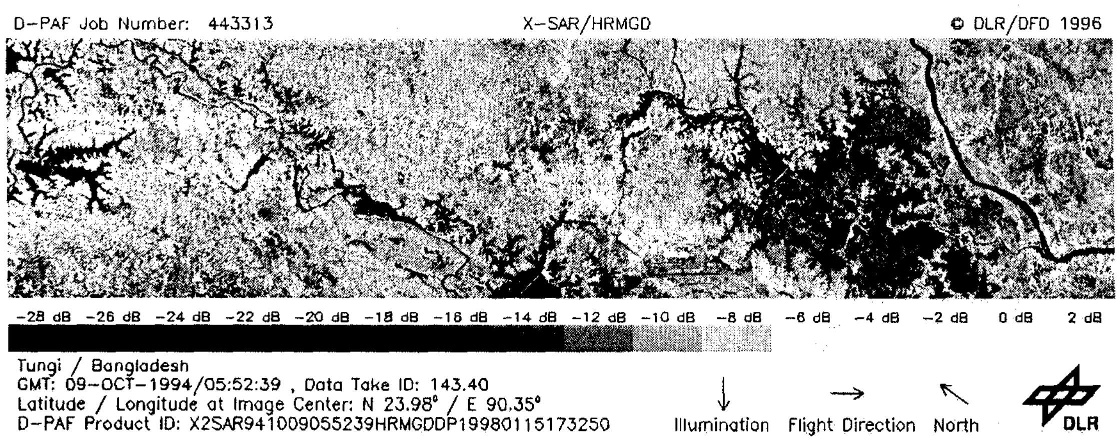
Ground Processed Image

Region and Change Detection

- Algorithms for water region detection and change detection in testing using X-SAR data



Identified water



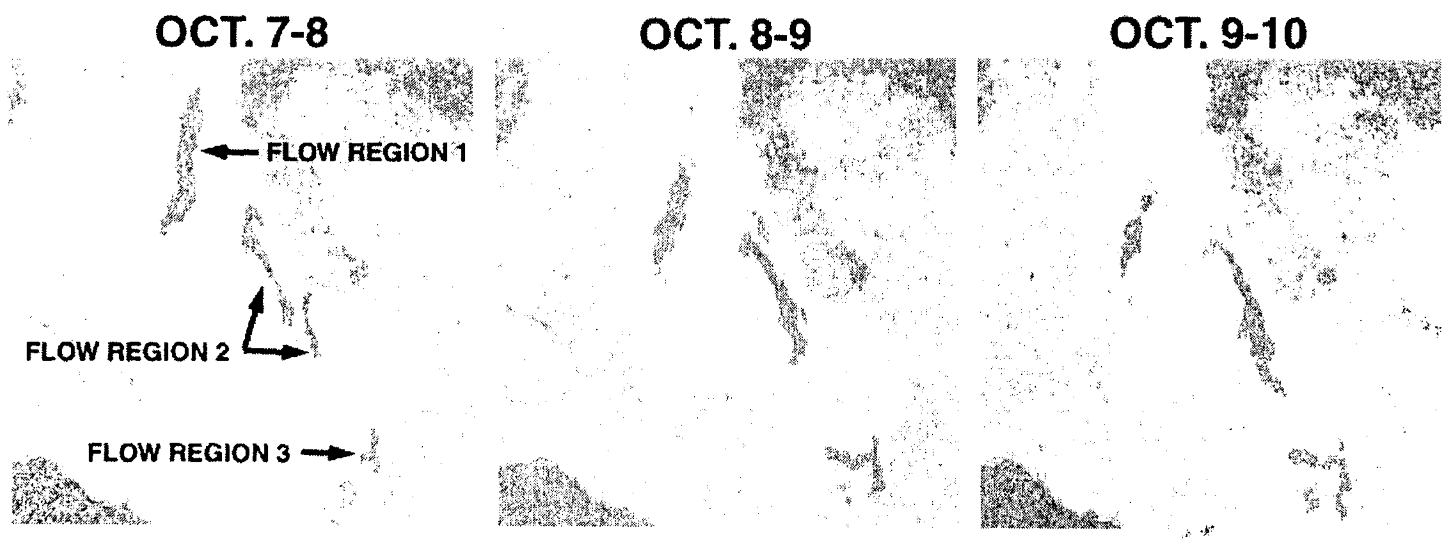
Raw image

1994 Bangladesh, X-SAR

Example: Lava Flow Detection

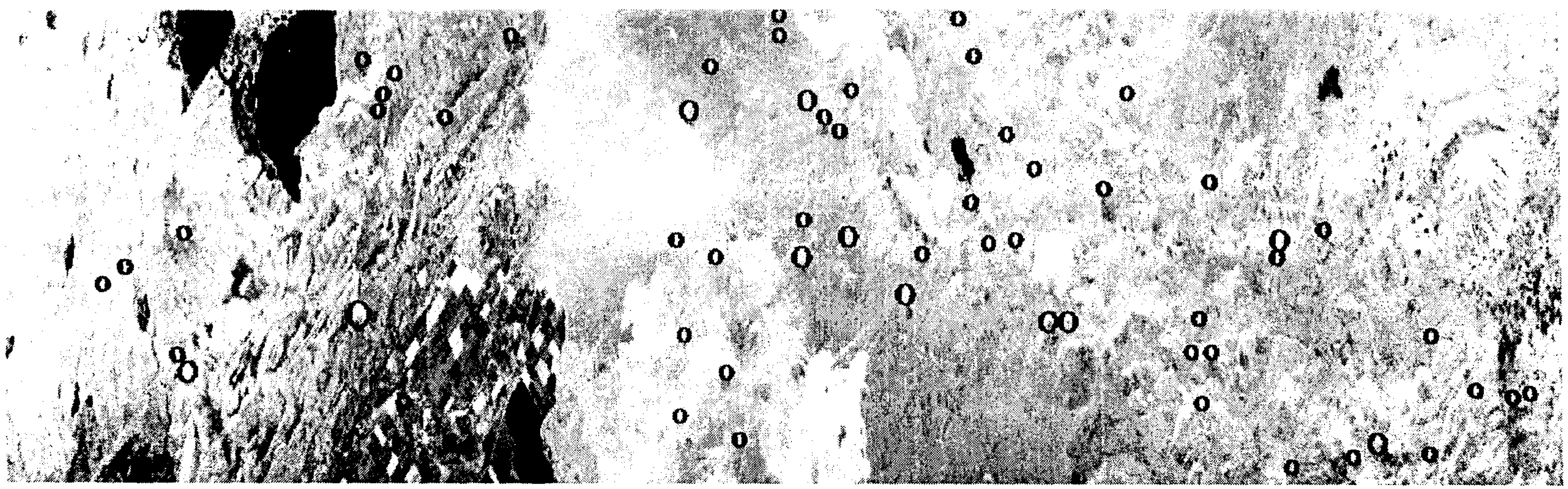
- C-SAR radar images indicating lava flow on Kilauea volcano, Big Island, Hawaii

- Science team analysis derived a >20 fold compression rate on subsequent images by downlinking only changed portions



Feature Recognition Algorithms

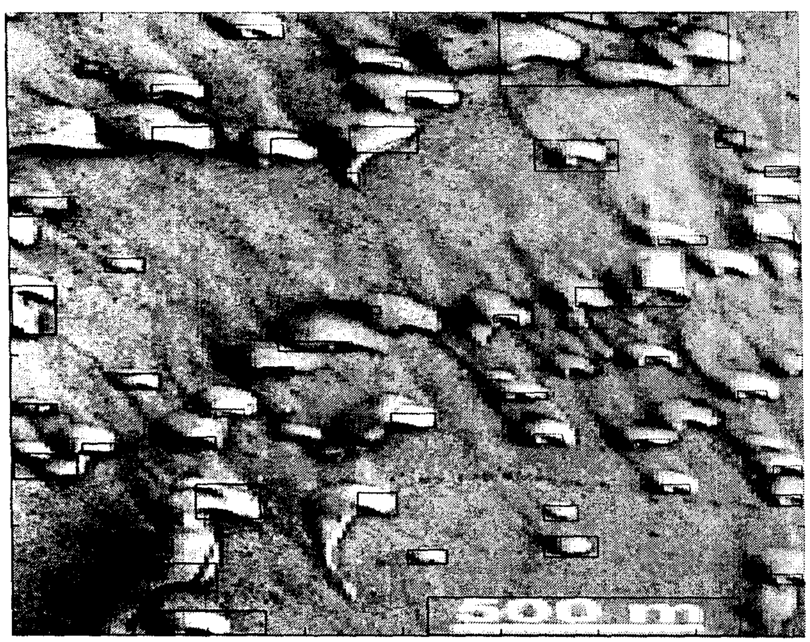
- Preliminary feature detection algorithms already being tested on lava cone X-SAR data
  - Circles indicate identified lava cones
  - Blue circles indicate highest confidence matches

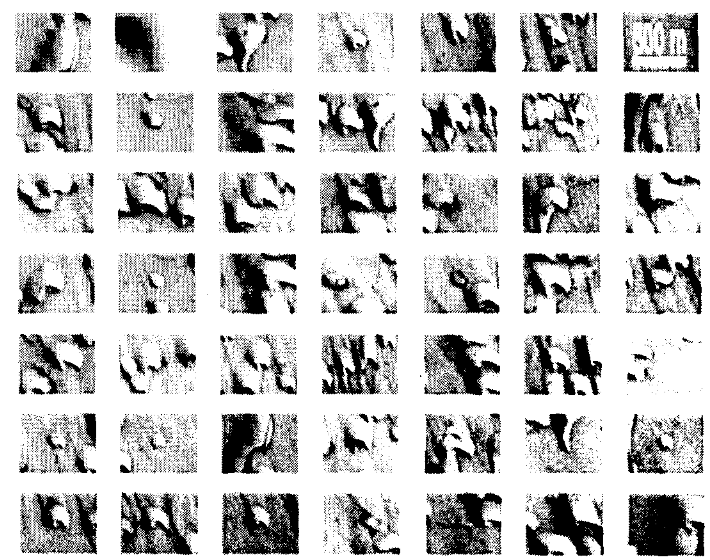


X-SAR image of Lava Beds National Monument, CA, USA image taken with X-SAR instrument flying onboard Space Shuttle Oct. 09, 1994

Discovery Algorithms

- Prototype visual discovery algorithm
- Identifies regions of an image that differ significantly from the local background
- Has successfully identified impact craters, volcanoes, sand dunes, ice geysers from sample image data





Mars Global Surveyor image – many of the identified regions are sand dunes

TS-21 Science Scenarios

- Monitor events such as:
  - Active volcanoes
  - Seasonal snowcap melt
  - Active flooding events
  - Ice formation/breakup
- Detect change via:
  - Registration and comparison (hard)
  - Comparison of derivative features (Centroid, mass boundaries)
- Reactions include:
  - Downlink whole image on change
  - Downlink changed portion
  - Downlink summary of changes (new boundary line segments)

Lava flow

Kilauea, HI

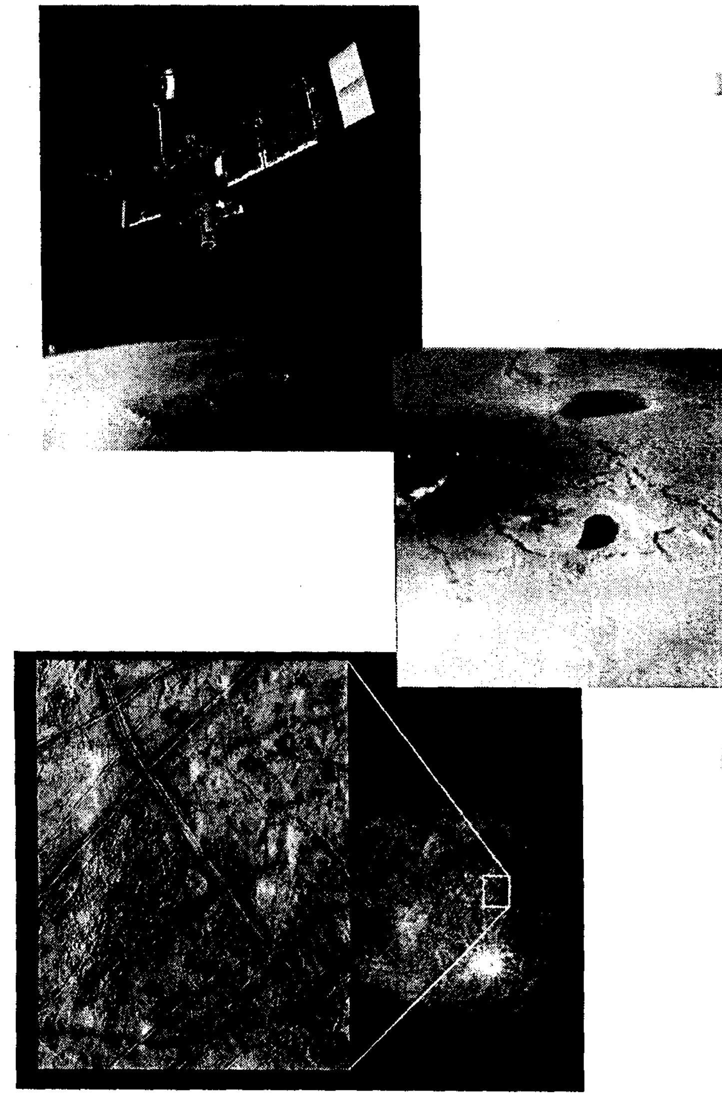
Calving

Icebergs

Flooding

Extraterrestrial Applications

- Planetary mapping
  - Searching for surface change (Mars, Europa, Io)
    - Mars surface monitoring (e.g., ice cap formation and retreat; movement of dunes)
    - Io volcano observer: requires autonomous capability to capture transient events
    - Europa surface change (e.g., as function of tidal stress)
  - Radar mapping of Venus and Titan, searching for change (evidence of recent and/or ongoing activity)



Io animation

Technology Component: Onboard Replanning

Steve Chien

Technology Component: Onboard Replanning

- CASPER use a model of spacecraft activities to construct a mission plan to achieve mission goals while respecting spacecraft operations constraints
  - Example goals: science requests, downlink requests, maneuver requests
  - Example constraints: memory, power, propellant, etc.

- TS-21 will utilize the CASPER continuous planning system onboard to replan to achieve newly derived science goals

What is Planning?

Achieve a state ⇨ Get 20 images of Kilauea caldera lava flow to ground science team

Perform a sequence of activities ⇨ Sequence of many

- Configure radar
- Free up memory
- Slew spacecraft
- Stabilize spacecraft
- Power on radar
- ...

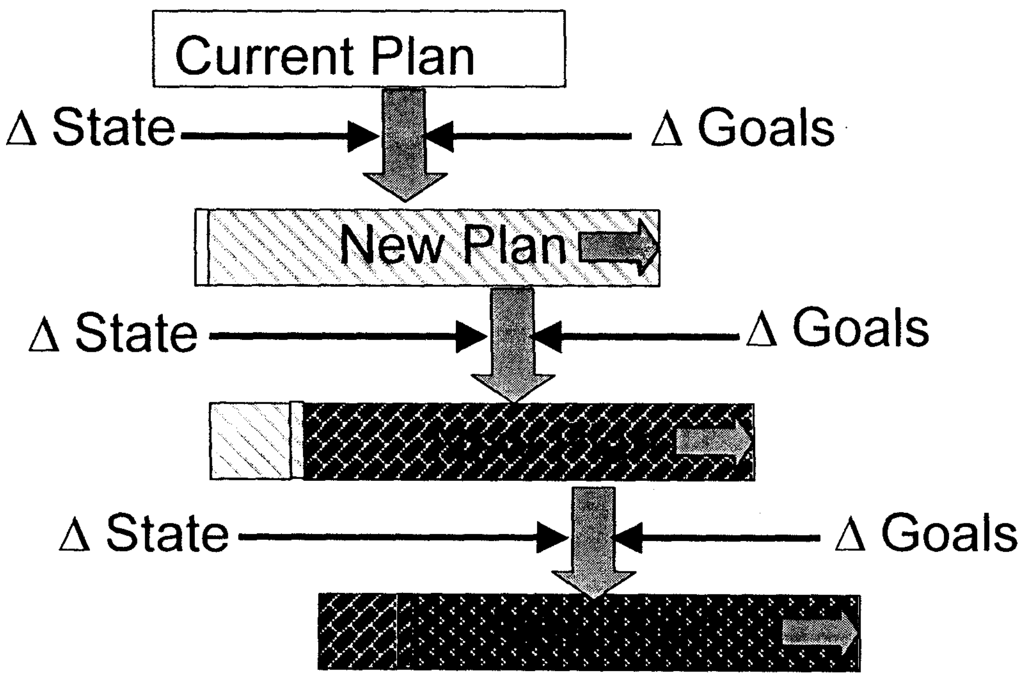
Uses Model of Activities

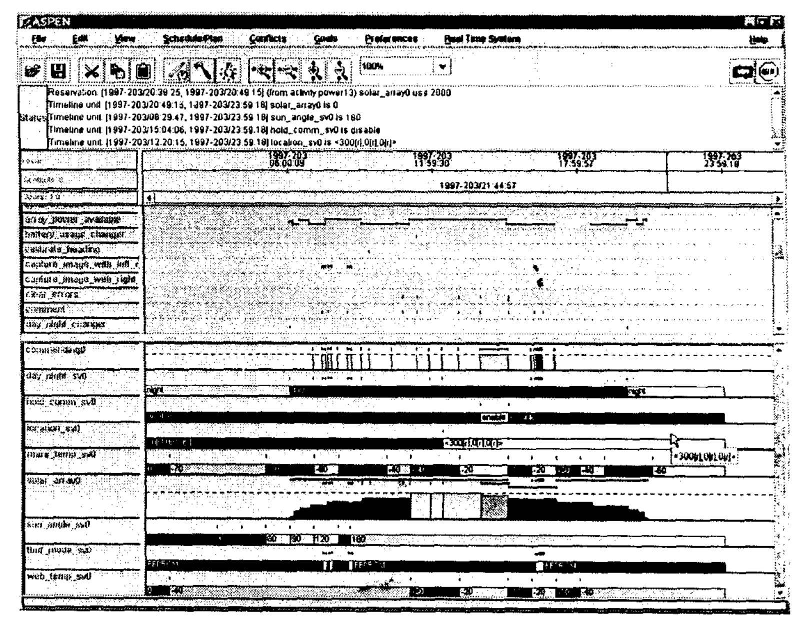
Resources	uses 600 W power; uses XXX memory
States	requires ACS state to be “Fixed Attitude”
Other Activities	Decompositions point_radar before turn_on_radar before…
	…

These models are then combined to model the world as it changes due to activities

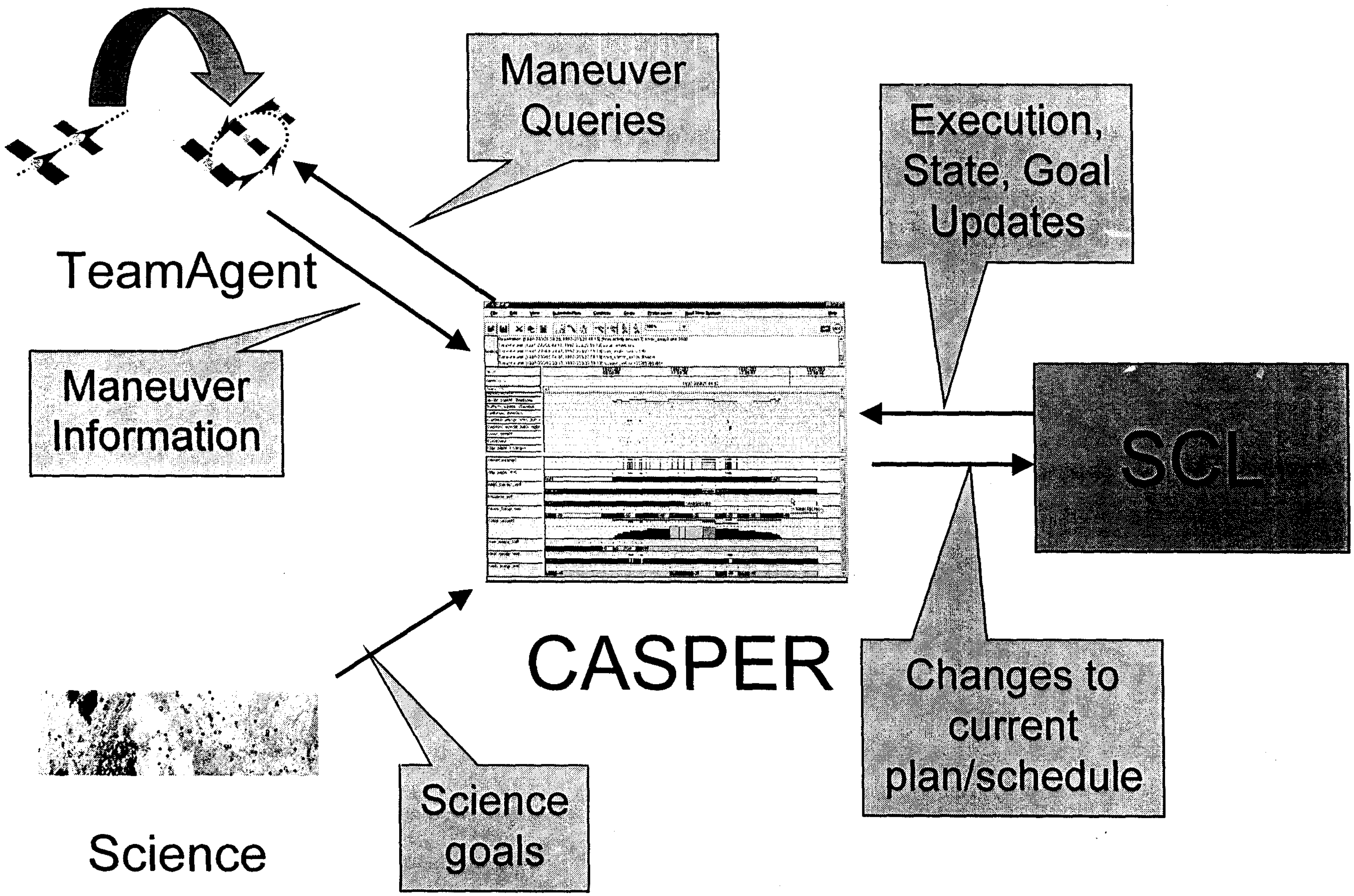
Onboard Replanning

- CASPER uses continuous planning techniques to achieve a response time in the 10s of seconds



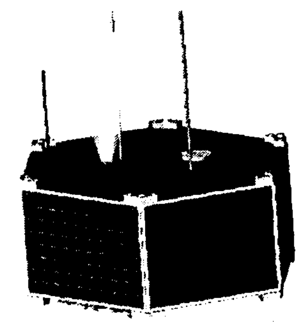


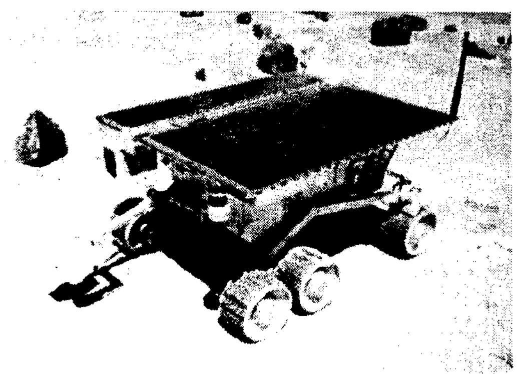
Onboard Replanning

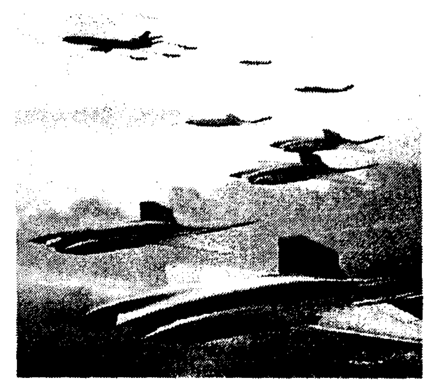


Other CASPER Deployments

- Also scheduled for flight on 3-Corner Sat (U. Colorado) 2002
  - 3CS flight also uses same CASPER/SCL integration software
- Also being applied to
  - Autonomous rover control (Rocky7, Rocky8)
  - Ground communications station control (CLEaR)
  - Unpiloted aerial vehicles (LMSW)
- Also being used as single agent in Teamwork/Coordination (rover & spacecraft)





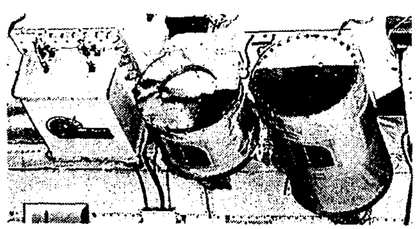


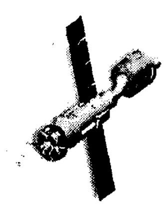
Technology Component: Robust Execution

Interface and Control Systems

Technology Component: Robust Execution

- Uses Spacecraft Command Language (SCL) developed by Interface and Control Systems
  - SCL integrates procedural programming with a
    - forward-chaining, rule-based system for
    - event-driven real-time processing
- In the ASC concept, SCL scripts will also be planned and scheduled by the CASPER onboard planner
- SCL is a mature software product used on many missions including several flights: Clementine I, ROMPS, DATA-CHASER, ICM for ISS, FUSE,…
- SCL to also be used in ground control of TS-21



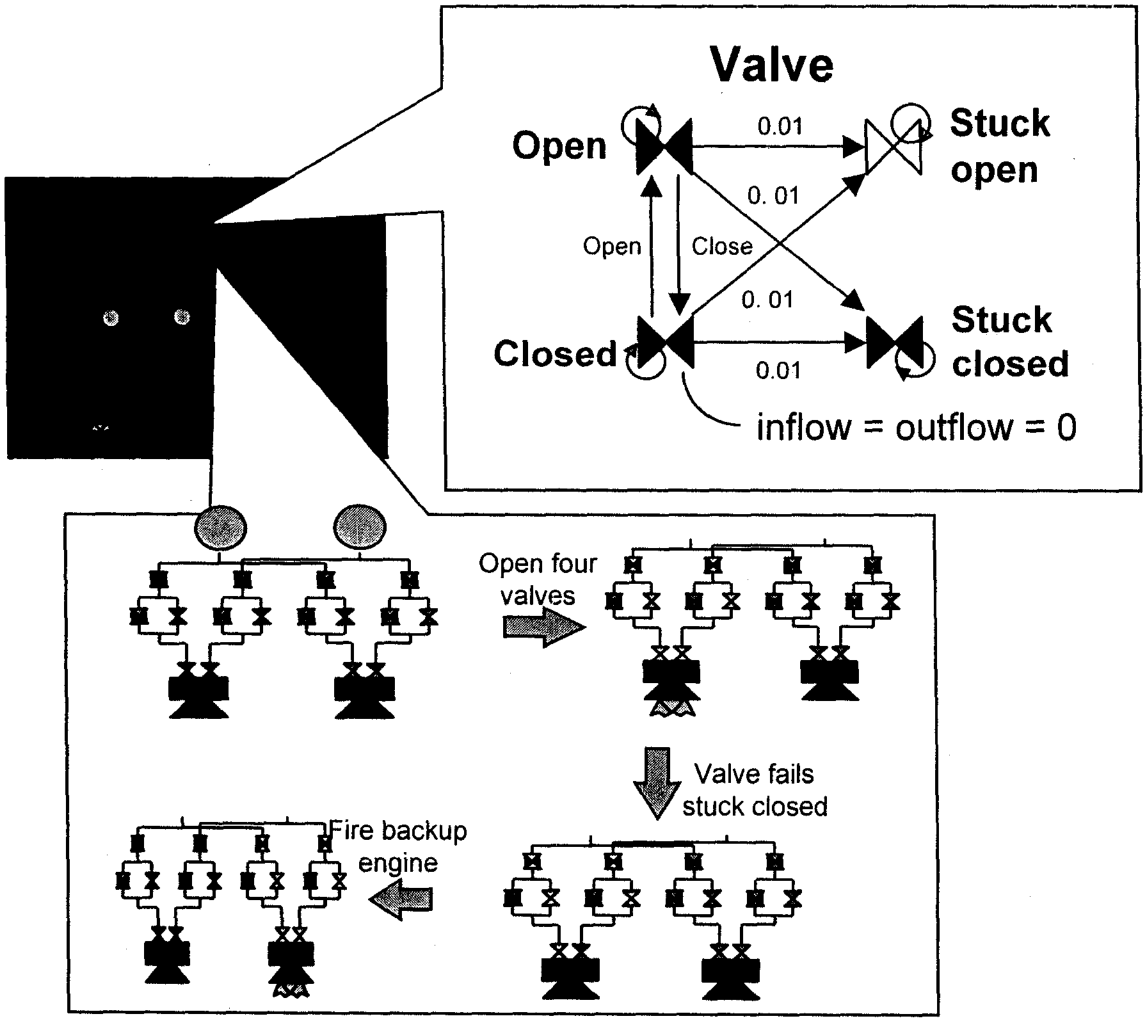



Technology Component: Mode Identification and Reconfiguration (MI-R)

Space Systems Laboratory, MIT

Interface and Control Systems

Model-based Mode Identification and Reconfiguration



Mode Identification

- uses a stochastic finite automata transition model of spacecraft systems to compute most likely states based on sensor readings and command logs

Reconfiguration

- uses same models to compute sequences to achieve desired configurations

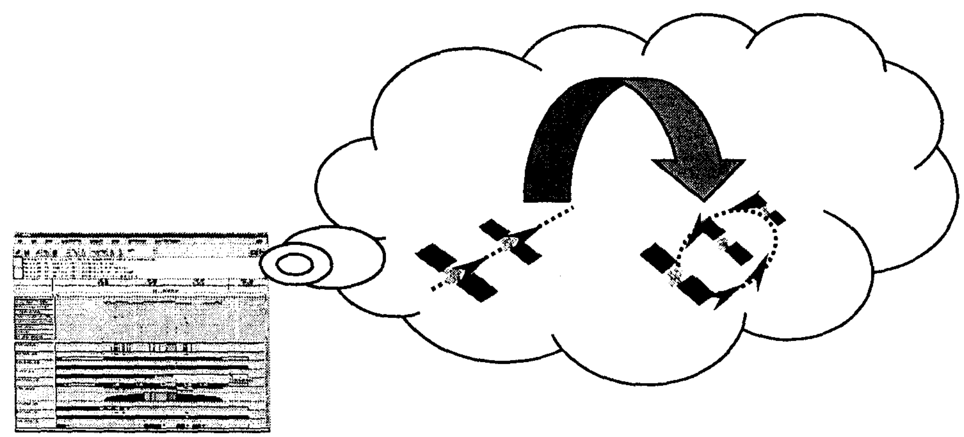
Technology Component: Onboard Cluster & Maneuver Management

Princeton Satellite Systems

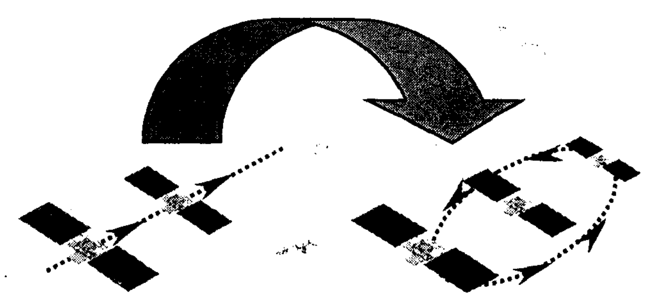
Onboard Cluster & Maneuver Management

- ObjectAgent (OA) and TeamAgent (TA) software developed by Princeton Satellite Systems (PSS)
  - OA provides *maneuver and orbit control* for single spacecraft
  - TA provides *formation flying layer* on top of OA

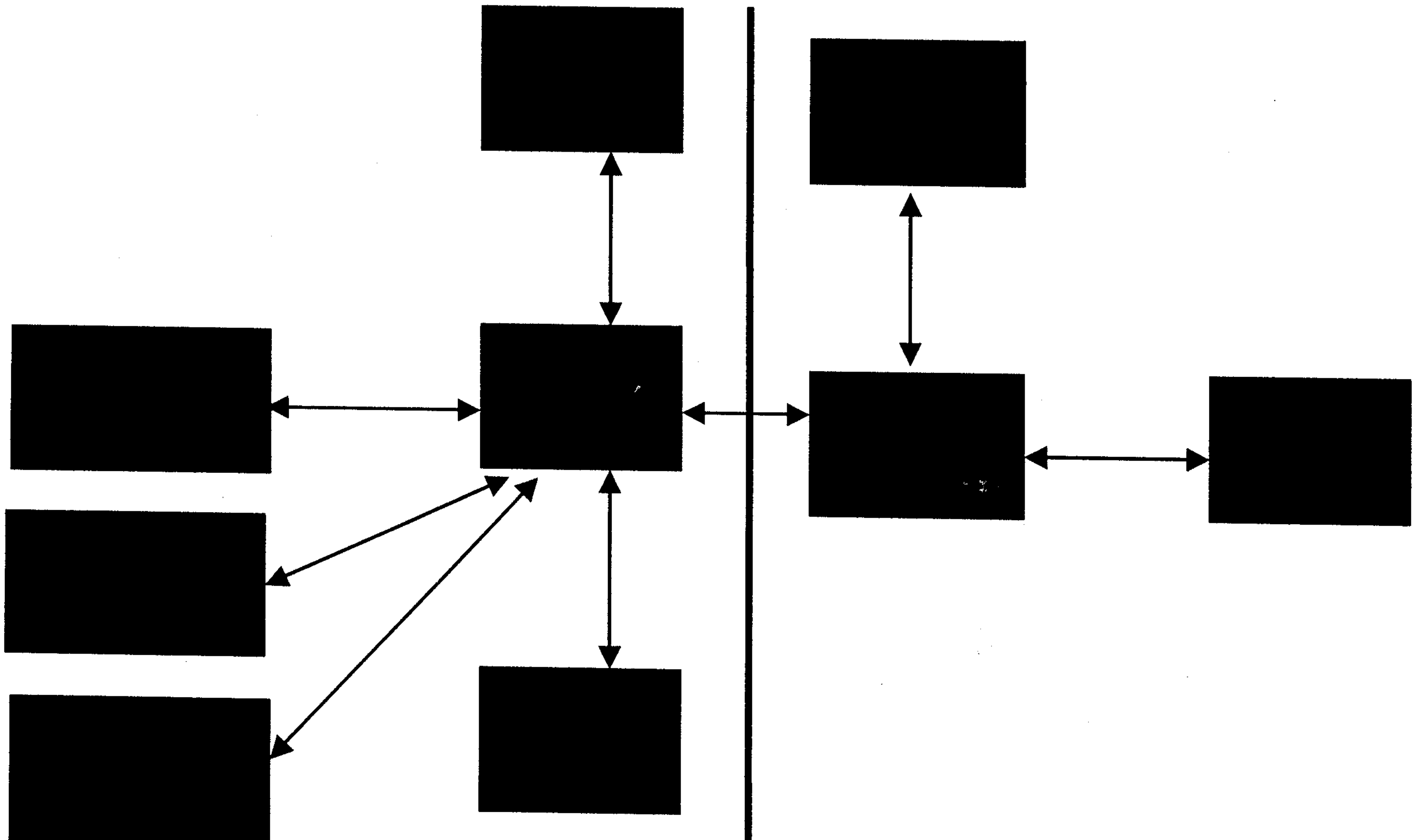
- OA/TA supports *plan time queries* from CASPER to compute visibilities, costs, and timing of maneuvers



- OA/TA also performs *closed loop control* of maneuvers at execution time



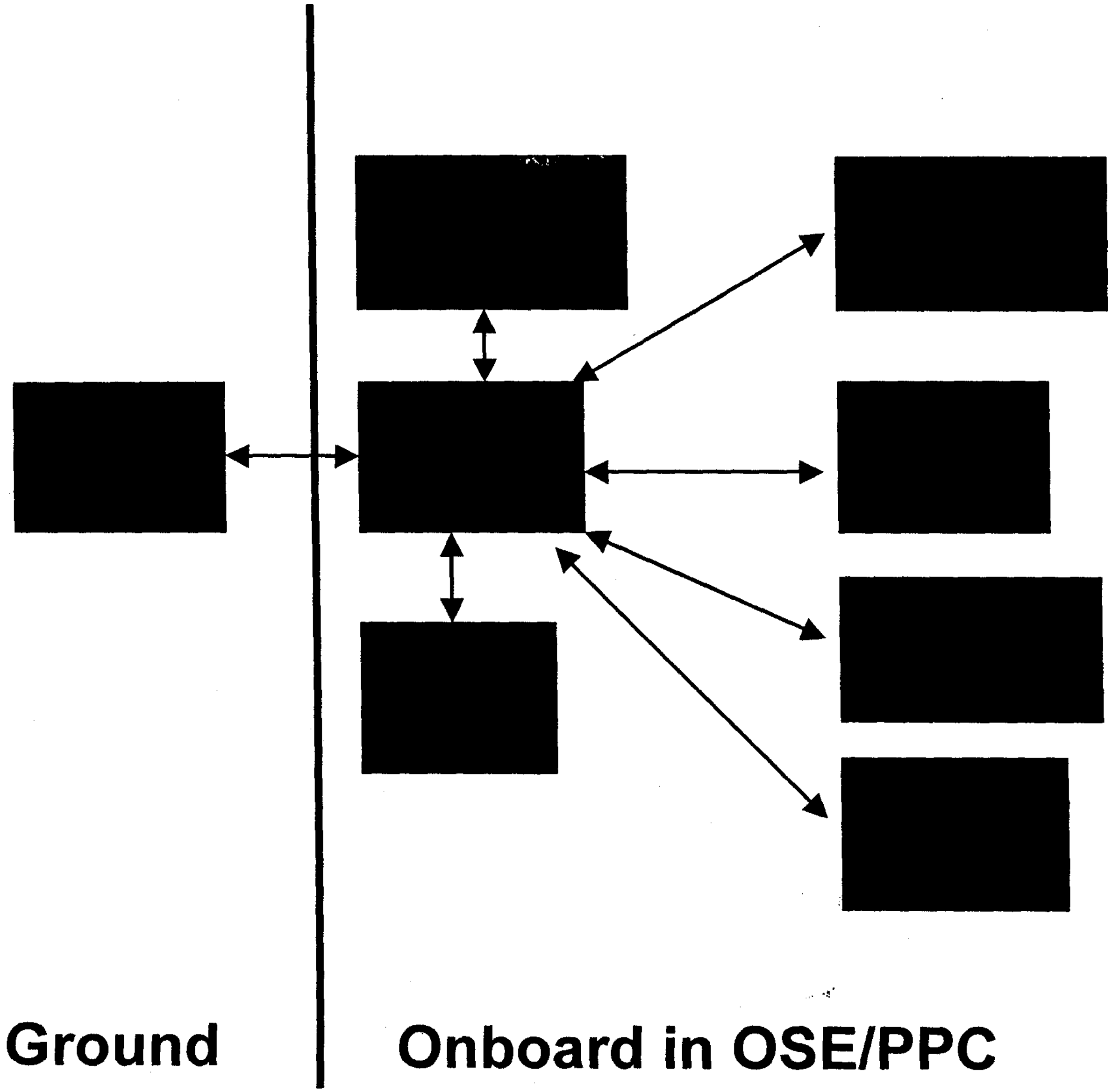
Current Software Architecture



Solaris Workstation Environment

Flight Environment OSE/PPC

Flight Software Architecture



Status of ASC

- Completing a prototype in a combination workstation/breadboard environment with demonstration in August 2001
  - Formation flying and robust execution already on flight processor

- Planning and science software on flight processor in March 2002

- Continue testing science detection algorithms on multiple SAR data sets

- Apply flight experience from the 3-Corner Sat mission to TS-21

Related Work

- Deep Space One Remote Agent Experiment
  - Demonstrated Batch Planning, Robust Execution, Mode Identification and Reconfiguration for two ~48 hour periods in May 1999
- Techsat-21 builds on RAX experience and adds
  - Control of spacecraft for days – weeks
  - Includes Onboard Science, Maneuvers and Formation Flying
  - Uses Continuous Planning to reduce response time to minutes
- 3 Corner Sat (Sept 2002 launch)
  - Demonstrated more limited use of replanning based on data validation
- PROB-A (ESA)
  - Emphasis on lower-level autonomy

Summary

- Using on-board software for planning, science data analysis, execution, fault detection, and cluster management will increase mission value by:
  - Returning only the most important science data
  - Returning less engineering data
  - Moving the labor-intensive spacecraft and science data analysis functions onboard the spacecraft
  - Allowing the spacecraft to be commanded with high-level goals
  - Allowing quick response to opportunistic and dynamic science events

Future missions will benefit from TS-21's use of integrated onboard autonomy

Information/Acknowledgements

- Web Site: http://asc.jpl.nasa.gov

- Funding:
  - New Millennium Program ST-6 Project
  - IPN-ISD Technology Program
  - Cross-Enterprise Technology Development Program

- CSMISS sponsored this lunchtime talk!